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Fractal characterization of Ultrasonic back scattered signals from Aluminium

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Abstract: For the first time the concept of fractal geometry is introduced to characterize backscattered discrete ultrasonic time domain signals from Aluminium. These signals possess unique fractal dimensions and remain invariant with the change in sampling rate of signal capturing. The fractal dimension of these signals evaluated by both the box counting method and the power spectrum method were found to be equal. The cause of similarity in the fractal dimensions of these signals obtained from the above two methods have been discussed.

Keywords: Fractal dimension, Ultrasonic Backscattered Signal, Aluminium

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1. Introduction

Materials were characterized for a long time by the measurement of ultrasonic velocity and attenuation[1,2]. These measurements usually require the transit time between two successive back wall echoes and their respective amplitudes in plane parallel specimens. Variation of amplitude of these successive back wall echoes are essentially due to the cumulative attenuating effect of the entire thickness of the sample. The intrinsic information of the scattered signals during the course of propagation of acoustic pulse inside the specimen is not taken care in these measurements. Several attempts were made to characterize materials by processing signals in this back scattered region[3]. However no definite universal results were obtained. In this paper for the first time an attempt has been made to characterize the ultrasonic signals (including the back scattered region) from polycrystalline metal like Aluminium (Al) with the help of fractal geometry.

When the scattered ultrasonic signals from Al were viewed on the oscilloscope, it appeared to us that these signal profiles could be a "fractal" and thus may possess an unique fractal dimension. If these time domain signals could be quantified using fractal geometry, a different understanding would be provided for interpreting these signals. It is this objective that motivated us to investigate the fractal characterization of the scattered ultrasonic signals from this material.

A significant concept which is associated with the geometrical properties of an object is fractal geometry, which was introduced by Mandelbrot[4]. Complex physical phenomena are better described by fractal geometry than by Euclidean geometry. So fractal concepts are finding applications in various frontiers of science and technology[5].

2. Estimation of fractal dimension of a time domain signal

There are a number of techniques for evaluating the fractal dimension of a signal. Here we consider the box counting method and the power spectral method to evaluate the fractal dimension of the signal.

Box counting method uses boxes to measure the length of a curve by covering it with square boxes of same size. The number of these same sized boxes needed to cover the line is counted. This is repeated for a series of different sized square boxes. The results are then plotted as the number of boxes (y-axis) versus 1/(length of square box) on a log-log plot. The fractal dimension D is equal to the slope of the plot. A computer algorithm has been developed to find the fractal dimension of captured back scattered ultrasonic signals by this box counting method.

Fast Fourier Transform (FFT) are carried out on the ultrasonic time domain signals in order to evaluate the fractal dimension of these time domain signals by the power spectral method. Power spectral density vs frequency are plotted on a log-log plot. A straight line fitted to this plot evaluates the fractal dimension D from the slope S of this plot[6] by the relation

$$D = (5 - S)/2 \quad \text{........(1)}$$

Along with fractal dimension, concepts like self-similarity and self-affinity are also important parameters of fractal geometry. Profiles of the fractal structure can be self-similar or self-affine. A self-similar object is composed of N (where N is any large integral number) copies of itself (with possible translations and rotations) each of which is scaled down by the ratio r in all Euclidian E co-ordinates from the whole i.e. a magnification of a certain portion of the object resembles in all respects the entire object. On the other hand, a self-affine object is composed of N copies of itself, each of which is scaled down by a different ratio $(r_1, r_2, \ldots\ldots r_E)$.

For self-similar fractal structures, fractal dimension remains invariant with the change in the method of estimation. Unlike self-similarity, different methods of estimating the fractal dimension of a self-affine structure may give different values[7].

3. The experiment

A broad band ultrasonic probe with central frequency of 5 MHz and of crystal diameter of 12.5 mm was used. The probe was excited by a pulser receiver unit and was used for both transmitting as well as receiving ultrasonic signals. Ultrasonic backwall echoes were obtained from the specimen of dimension 50mm x 50mm x 9.92mm by placing the probe at a fixed location. Enormous care was taken to maintain the plane parallity of the specimens used for this investigation. The time domain signals from the specimen were sampled at a sampling rate of 10 ns. Signals were initially captured on a digital oscilloscope and then the data was loaded on a personal computer through RS 232 interface To evaluate the power spectrum of these time domain data, FFT was carried out on these time domain ultrasonic signals.

The number of sampling points were chosen to be equal to 4500 for all the captured signals. This was large enough to give an accurate estimation of fractal dimension, while at the same time reasonable enough that the computational time does not become prohibitively long. The box counting method was utilized to calculate the fractal dimension of the stored time domain scattered signals. To judge the invariance of the fractal dimension, the sampling rate of the captured signals were changed to 20 ns and only 2700 sampling points were taken for the evaluation of the fractal dimension.

4. Results and discussions

A simple examination of the temporal evolution of the back scattered ultrasonic signals (Fig 1) does not provide much information except for its seemingly random behavior. When observed closely, the signals seem to have either a self similar profile or a self affine one.

For the box counting method the fractal dimension was evaluated from the slope of the plot of log (Number of square boxes needed to cover the signal) against -log (length of the squared box used). The length of the square box varied between 0.1 to 0.01 by making the total span of the entire signal of unit length. Fig. 2 shows such a plot for Al. The slope of this curve is estimate to be 1.5798 which is the fractal dimension.

In the power spectral method the fractal dimension is estimated from the plot (linear part) of power spectral density against frequency on a log-log plot with help of equation (1). Fig 3 shows such a plot with fractal dimension 1.5809.

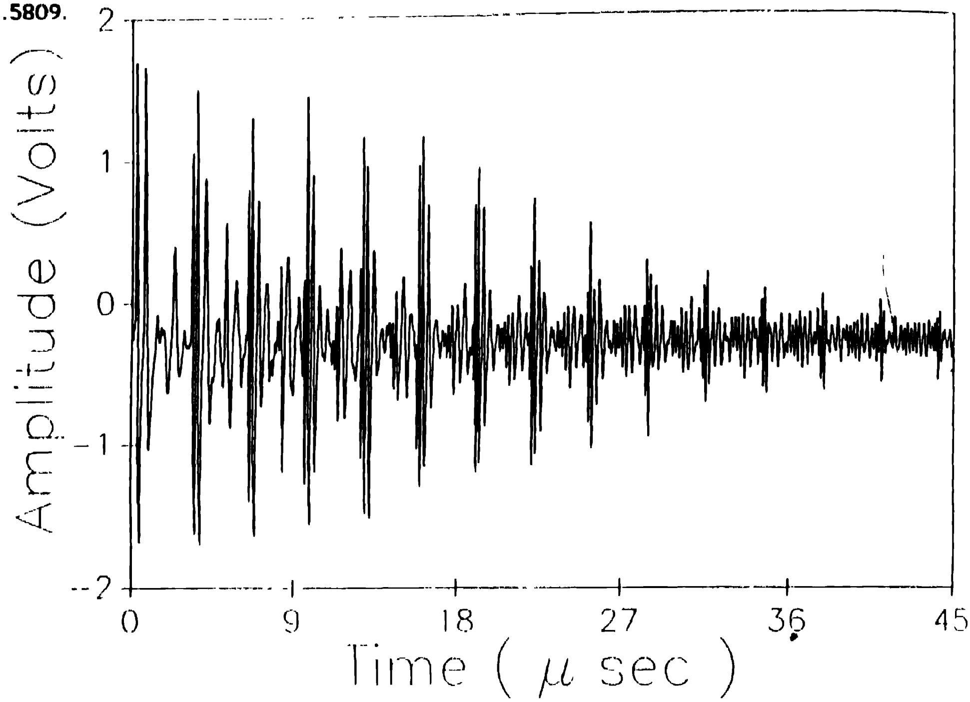

Fig.1 Time domain ultrasonic signal from polycrystalline Aluminium captured at a sampling rate of 10 ns.

It is observed that the fractal dimension of the time domain signals estimated by the above two different methods remains invariant for Al. The above result can be justified on the basis of a careful examination of the temporal evolution of the scattered signals obtained from Aluminium. The time domain signal of Al seems to possess a sufficient amount of back scattered noise sandwiched in between two back wall echoes. This characteristic scattering in Al renders a self similar profile to the time domain scattered signal, which is reflected by the fact that the estimation of fractal dimension by the two methods remains the same[7]. The acoustic wave scattering is closely related to the microstructure, so estimation of fractal dimension will give more information about the microstructure if the exact scattering mechanism is investigated.

Fractal dimension estimated with sampling rate of 10 ns (with 4500 data points) and with sampling rate of 20 ns (with 2700 data points) are found to be identical by box counting method. This observation is in harmony with the theoretical fact that fractal dimension is independent of the time resolution

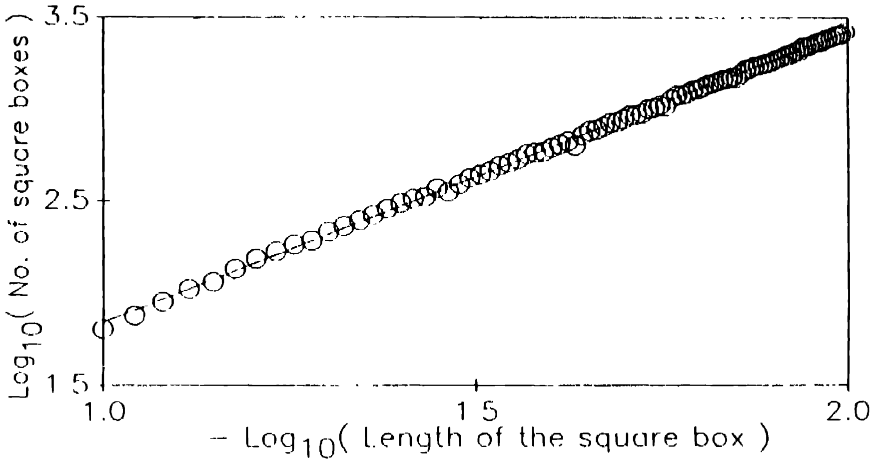

Fig.2 **Plot of Log_{10}(No. of square boxes needed to cover the signal) against $-Log_{10}$(Length of square box) for time domain ultrasonic signal from Aluminium.**

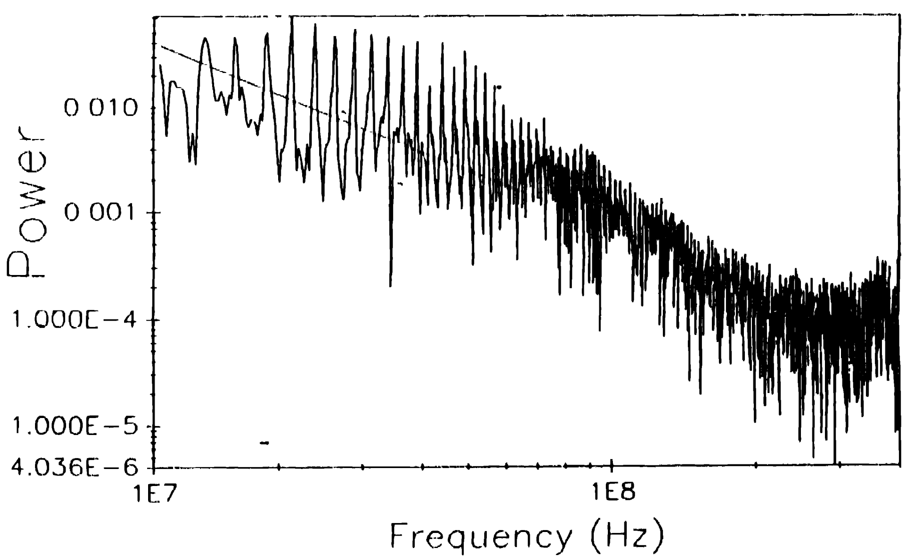

Fig.3 **Power spectrum of the time domain ultrasonic signal from Aluminium.**

of the signal[4].

5. Conclusion

The use of fractal geometry to interpret the time domain scattered signals from Aluminium shows that it can be used to characterize the different scattering mechanism present in various materials. Since these signals possess the characteristics of fractal, they can be very well used to explain various physical properties of materials. They can also be used for the microstructural analysis of various materials.

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